DECOMPOSITION KINETICS DURING DIRECT PHASE TRANSFORMATION IN Y_2Fe_{17} MAGNETIC ALLOY

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Kinetics of decomposition of Y_2Fe_{17} alloy during hydrogen-induced direct phase transformation, i.e. decomposition on YH_2 hydride phase and α-Fe phase of iron of initial phase of Y_2Fe_{17} magnetic alloy in hydrogen atmosphere has been studied. It has been established that, as the temperature increase from 610 to 750˚C, a direct phase transformation significantly accelerates. Activation energy of transformation process determined from kinetic data varying from 163 up to 242 kJ/mol that it is correspond to the values of activation energy of the iron atoms diffusion in R–T type alloys. It is shown that phase transformations kinetics in the investigated interval of temperatures is controllable by diffusion of iron atoms to growing new α-Fe phase centers.

Исследована кинетика распада сплава Y_2Fe_{17} в ходе индуцированного водородом прямого фазового превращения, т.е. процесса распада в атмосфере водорода исходного сплава Y_2Fe_{17} на гидридную фазу YH_2 и α-Fe фазу железа. Установлено, что при повышении температуры от 650 до 750˚С прямое фазовое превращение значительно ускоряется. Энергия активации процесса превращения определенная из кинетических данных варьируется от 163 до 242 кДж/моль, что соответствует значениям энергии активации диффузии атомов железа в сплавах типа R-T. Показано, что кинетика фазовых превращений в исследуемом интервале температур контролируемой диффузией атомов железа к растущим новым центрам α-Fe фазы.

At present the intermetallic compounds of R_2M_{17} (R=Sm, Y, Dy, Ho, Gd) type have attracted much attention because of their interesting magnetic properties [1,2]. In particularly, R_2M_{17} compounds demonstrate very interesting magnetic phenomenon during their interaction with interstitial atoms (H, N, C, B) [3-5]. For instance, the new perspective technology well known as a HDDR-process (Hydrogenation-Decomposition-Desorption-Recombination) in R_2M_{17} type alloys (Sm_2Fe_{17}, Sm_2Co_{17}, $Nd_2Fe_{14}B$ etc.) alloys for permanent magnets allows improve their structure and magnetic properties by hydrogen-induced reversible phase transformations [6].

The most significant aspect of the HDDR process is that there is a dramatic change in the microstructure from an initial grain size of typically ~150μm to a very fine, uniform grain size of about 0.1-0.3μm [6].

In particular, at HDDR-treatment the Y_2Fe_{17} alloy undergoes the direct hydrogen-induced phase transformation at temperatures above 500˚C with decomposition of initial alloy on hydride YH_2 phase and α-phase of Fe that can be described by the following scheme:

$$Y_2Fe_{17} + H_2 \rightarrow YH_2 + \alpha\text{-Fe} \qquad (1)$$

Then, the reverse phase transformation takes place during hydrogen evacuation at higher temperatures with recombination decomposed phases into initial Y_2Fe_{17} matrix phase and can be described by the following reaction:

$$YH_2 + \alpha\text{-Fe} \rightarrow Y_2Fe_{17} + 2H_2\uparrow \rightarrow Y_2Fe_{17} \qquad (2)$$

And finally, after the completion of recombination stage the treated alloy as a rule consist of the nanocrystalline phase of Y_2Fe_{17}.

It is obviously that the clear outstanding of kinetic features of the above hydrogen-induced phase transformations will allow in follows to control microstructure and magnetic properties of this alloy. For Y_2Fe_{17} alloy above-mentioned kinetic peculiarities have been not known yet until present and therefore, the main goal of present work was to investigate the features of kinetics of the hydrogen-induced direct phase transformation (1) in Y_2Fe_{17} alloy at temperatures range of 610-750˚C in hydrogen pressure of 0.1 MPa. Samples of Y_2Fe_{17} alloy were prepared by arc melting in an argon atmosphere of high purity. All kinetic experiments by investigations of kinetics of direct hydrogen-induced phase transformation has been carried out on special hydrogen-vacuum equipment using a special magnetometric Sadikov's method.

Thus, heating of an alloy Y_2Fe_{17} in hydrogen atmosphere results in development of direct phase transformation leading to alloy decomposition with formation of a hydride YH_2 phase and phase α-Fe (see the equation (1)) which was established by X-ray difraction experiment.

The results of research of kinetics of hydrogen-induced direct phase transformation in Y_2Fe_{17} alloy are generalized in Fig. 1 in form of kinetic curves.

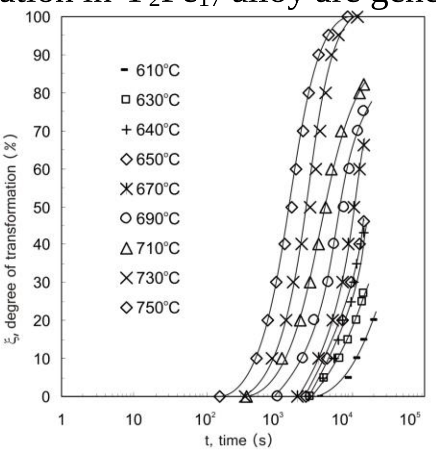

Fig. 1. Kinetic curves for direct hydrogen-induced transformations in Y_2Fe_{17} alloy at different isothermal temperatures in P_{H2}=0.1 MPa.

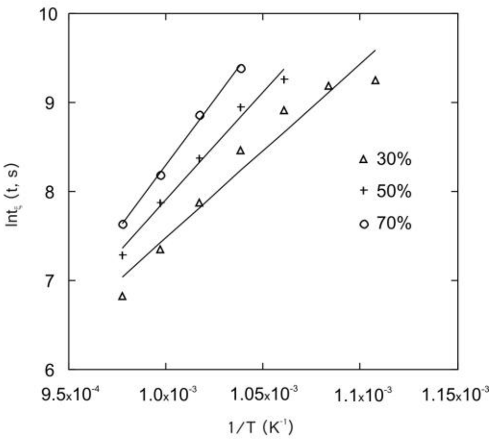

Fig. 2. Dependence $\ln t_\xi$ on 1/T for hydrogen-induced direct phase transformation in Y_2Fe_{17} alloy.

As can be seen from Fig. 1, with increasing of transformation temperature in narrow interval (140˚C) from 610˚C up to 750˚C the direct phase transformation lead to very strong acceleration of transformation in some order of magnitude. Because of this, it is necessary also to note, that at all temperatures there is a noticeable incubation period of a phase transformation (from 0.33×10^4 s at 640°C to 0.015×10^4 s at 760^{o}C). As can be seen in Figures 1, the shape of the kinetic curves with a gradual slowdown of the transformation rate with decrease temperature and also dependence of the incubation period on the temperature let us suggest [7] that phase transformations develop by the mechanism of nucleation and growth.

Further, as well known from classic kinetic theory of phase transformations in condensed state [7], in particular in accordance with Becker-Döering model of nucleation kinetics [8-9] if plots dependence $\ln t_{\square}$ on $1/T$, where $t_{\square}$ is the transformation time, which it is necessary for reaching of some degree of transformation $\square$ and T is the transformation temperature, we can determine an effective energy of phase transformation process. For this goal experimental data from Fig. 1 were re-plotted in co-ordinates $\ln t_{\square}$ versus $1/T$ which are shown in Fig. 2. The slopes of the straight lines give us the values of the effective activation energies for hydrogen induced direct phase transformation in Y_2Fe_{17} alloy. The obtained values of an activation energy determined for some degrees of transformation varying from 163 up to 242 kJ/mol. Thus, above obtained values of an activation energy correspond to the values of an activation energy of the iron atoms diffusion in R–T alloys (where R is a rare-earth metal, T – a transition metal) ~250 kJ/mol [10], whereas activation energy for hydrogen atoms diffusion in R–T alloys is 45 kJ/mol [10].

Thus, can be believed that the above investigated direct hydrogen-induced phase transformations in Y_2Fe_{17} alloy are controllable by diffusion of iron atoms to growing α-Fe phase centers.

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